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Explanation of the Astronomical Field Tables

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EXPLANATION

OF THE

ASTRONOMICAL

FIELD TABLES

FOR THE USE OF

PROVINCIAL LAND SURVEYORS IN CANADA

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BULLETIN 37

OTTAWA
SURVEYOR GENERAL'S OFFICE
1918

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PREFACE.

At the request of the Association of Ontario Land Surveyors, a special issue of the Astronomical Field Tables for use in Canada, elsewhere than on the survey of Dominion Lands, has been authorized by the Minister of the Interior. To adapt the tables to such use, the latitude has to be taken as argument instead of the number of the township, and they have to be extended to latitude 42°, the other tables not extending farther than latitude 49°.

The following explanations and directions are those of the Manual of Survey of Dominion Lands amended to suit the new tables.

DESCRIPTION OF THE ASTRONOMICAL FIELD TABLES.

The object of the Astronomical Field Tables is the determination of the astronomical meridian or the bearing of a line by means of a sidereal watch and the theodolite employed by the surveyor for his work in the field. They consist of two parts: the tables of the altitude and azimuth of the pole star and the tables of the sun.

An observation of the pole star is the simplest and most accurate means of referring a line to the meridian, either for obtaining the direction or for checking its production. The Astronomical Field Tables furnish the data for making the observation at any time of the day. With a suitable telescope, the observation can be made in full daylight, thus avoiding the difficulties and inconvenience of night observations. The tables are for short periods in several consecutive years; the periods are so selected as to reduce to a minimum the error resulting from the employment of a mean position for the star. The dates vary somewhat from year to year, typical periods being:

October 8 to December 14, 1916,
August 14 to October 6, 1917,
June 2 to August 9, 1918,
and
December 15, 1916 to March 13, 1917,
March 10, 1918 to June 2, 1918.

The argument of the tables given in the second column is the sidereal time for every ten minutes.

In the first column is the number of minutes to be added to or subtracted from the latitude for obtaining the altitude of the star, in order to set the telescope for finding the star.

The other columns give in degrees, minutes and decimals the azimuth of the star for every 2° of latitude from 42° to 56°.

When the approximate direction of the meridian is known, the telescope can, by means of the table, be directed on the star. When the star is discovered in the field, it is used for determining the direction of the meridian.

Knowledge of the sidereal time within one minute being required for the azimuth observation, one of the tables gives the sidereal time of meridian transit of suitable stars for the determination of the watch correction. The last column of this table contains the north polar distance of each star, for calculating its altitude in order to set the telescope so that the star shall cross the field.

The sidereal time at mean noon given in the tables, serves as a first approximation for setting the sidereal watch from a mean time clock.

The diagram for converting to hours and decimals a longitude expressed in degrees is for interpolation in the tables of the sun.

The convergence diagram gives, between the latitudes of 42° and 56°, the convergence of meridians for one mile of departure: it is used for changing the meridian to which an azimuth or a bearing is referred.

The tables of the sun are merely the reproduction, in compact form for the pocket, of the Nautical Almanac Tables. The right ascension is for the determination of the watch correction by the meridian transit of the sun: the declination is for finding the azimuth when the weather is not clear enough for observing the pole star.

THE OBSERVATION OF STARS IN DAYLIGHT.

With a telescope of small aperture, a star can be seen in daylight only in perfectly clear weather; the slightest haze hides it. Its visibility depends upon the magnitude of the star, its angular distance from the sun, and the latter's altitude above the horizon. A resolving power of 20 or 22, Surveys Laboratory scale, is sufficient for the pole star; it is obtained with a good telescope of inch and a half aperture and a magnification of 20 to 25. With such a telescope, the laboratory experts, who make the observation frequently in testing instruments submitted for their examination, can in clear weather see the star at noon throughout the year. A sur-

veyor with little or no practice may not be able to do as well but he will have no difficulty in seeing the star an hour or two after sunrise or before sunset. A telescope of inch and a quarter aperture may answer the purpose but not quite as well. Twenty is the limit of the resolving power for this aperture and it is obtained only with a telescope of exceptional quality and a high magnification, about 30. If a telescope of smaller aperture is used, it is necessary to wait until the sun is on the horizon or even below, and it may then be too dark for reading the theodolite's graduation or for seeing the pickets of the survey.

An erecting telescope is not suitable. Besides the loss of power due to the multiplicity of lenses, the aperture of such a telescope in a surveyor's theodolite is too small for affording the power required.

Ramsden's ocular and other oculars of a like construction are quite suitable but they oblige the observer to take an uncomfortable position when looking at the pole star: to obviate this drawback, a diagonal eye-piece must be resorted to. Notwithstanding the inconvenience of Ramsden's ocular, many surveyors use it exclusively; their prejudice against the diagonal eye-piece is but partly justified.

The loss of power due to a well-adjusted diagonal eye-piece of good construction is small, but eye-pieces are found, even among those coming from

well-known opticians, which reduce the power one-half. Any eye-piece in which the reflector is a silvered surface must be discarded because it tarnishes too easily. The long diagonal must be used only after verifying the adjustment and making sure that its aperture diaphragms, real or virtual, do not reduce the effective aperture of the telescope. At the Surveys Laboratory, the best results have been obtained with a Ramsden's ocular in which a prism with front face spherical is substituted for the eye lens.

To see stars in daylight, it is essential that the telescope be focussed very accurately; otherwise the image is spread out and not bright enough to be visible. Focussing on a terrestrial object is not sufficient; it must be done on a star in the evening when there is still light enough to see the threads of the diaphragm. A slow moving star, not too bright, is selected and is brought under the vertical thread of the telescope. If when the eye is displaced to the right or left, the star leaves the thread and appears to move, the object glass is not correctly focussed; it must be adjusted until the movement ceases. This position is marked with a sharp knife on the draw tube: the mark indicates solar focus which is the same for all observers. The ocular is next adjusted and the position selected which gives the sharpest and brightest image. The position is marked with a knife on the tube of the ocular: it

varies with the observer. After this preliminary operation, the marks are used whenever solar focus is needed.

For observing either for time or for azimuth, the telescope has to be directed upon the star; the procedure is explained farther on. The field is then scanned carefully and systematically; with a little patience, the star is soon discovered. Once found, it appears so plain that it is always a subject of surprise that it was not seen sooner. A little movement given to the telescope by means of the tangent screw of the vernier is of assistance in perceiving it.

OBSERVATION FOR AZIMUTH.

For directing the telescope on the pole star, the altitude is calculated by adding to the latitude, or subtracting from it, the number of minutes in the first column of the table. If the bearing of the reference object is known approximately, the telescope is directed by means of the azimuth of the pole star taken from the table. The vernier of the horizontal circle is set to the graduation representing the bearing; after releasing the lower clamp, the instrument is turned in the direction of the reference object; the lower clamp is fastened and the fine adjustment finished with the lower tangent screw. Releasing the vernier clamp, the angles read on the horizontal circle are now bearings; for finding the

star, the convergence of meridians can generally be neglected and the angles be considered as azimuths. It is then sufficient to set the vernier of the horizontal circle to the azimuth of the pole star, taken from the table, and the vernier of the vertical circle to the altitude already calculated, in order that the star may be in the field of the telescope.

When no bearing is known, even approximately, the compass is resorted to.

With a theodolite in which the compass is fixed to the vernier plate, the vernier of the horizontal circle is set to the azimuth of magnetic north and after releasing the lower clamp, the instrument is turned until the point of the needle coincides with the zero of its index. The lower clamp is fastened and the fine adjustment completed with the lower tangent screw. Releasing the vernier clamp, the angles read on the horizontal circle are now astronomical azimuths and the observation proceeds as before.

With a theodolite fitted with a box compass under the horizontal circle, the simplest way is to measure the magnetic bearing of the reference object, to correct it for the variation of the compass, and to proceed as when the azimuth is known approximately.

In all cases, the index error of the needle must be allowed for if it exceeds a few minutes. The magnetic needle being subject to considerable variations

this method is less certain than the preceding one. If after a thorough exploration of the field the star is not seen, the telescope is turned slowly, by means of the vernier tangent screw, one or two degrees to the right and left of its mean position.

After finding the star, it is brought under the vertical thread of the telescope by means of the vernier tangent screw, the watch time is noted and the two verniers of the horizontal circle are read.

The complete observation is made in the two positions of the instrument, vertical circle to the right and to the left. The position is changed by revolving the vernier plate 180° and transiting the telescope. The star is again brought under the vertical thread, the hour of the watch is noted and the two verniers of the horizontal circle are read. The observation is completed by pointing on the reference object and reading the two verniers.

The instrument must be levelled with the greatest care. A slight inclination of the vertical axis in the meridian does not matter, but any deviation perpendicular to the meridian causes, within the limits of latitude of the tables, an error in the azimuth from 0.87 to 1.55 times as great.

The following examples show how the observations are made, recorded and calculated.

EXAMPLE NO. 1.

POLE STAR OBSERVATION FOR AZIMUTH

Date: June 9, 1917

Station: N. corner lot No 1, 7th Concession, Township of Chatham, Ontario Lat. 42° 28' Long. 82° 16'

Orientation Mer.: N. corner lot No 12, 7th Concession

Ref. Object: W. corner lot No 1, 7th Concession.

Face	H.C.R. on R.O.	H.C.R. on Polaris	Watch Time
Right	227° 30·0	358° 36·5	9h 43m 13s
Left	47 31·0	178 37·5	9 45 39
Mean	227° 30·5	358° 37·0	9 44 26

Watch correction	+ 2 27
Sidereal Time	9h 46m 53s
Tabular azimuth for 9h 40m, lat. 42° 00'	358° 43·1
Variation for 6m 53s	+ 1·6
Variation for 28' latitude	- 0·6
Convergence for 3·0 miles east	+ 2·4
Bearing of Polaris	358 46·5
H.C.R. on Polaris	358 37·0
Correction of H.C.R.	+ 9·5
H.C.R. on Ref. Object	227 30·5
Bearing of Ref. Object	227° 40·0

EXPLANATION.

The surveyor has to retrace the line between the 7th and 8th concessions of the township of Chatham, Ontario. He selects as orientation meridian, from which all bearings of the survey shall be reckoned, the astronomical meridian of the centre of the line, which is the northerly corner of lot No. 12.

He plants a picket at the westerly corner of lot No. 1 and sets up his theodolite at the northerly corner of the same lot. According to the township plan, the direction of the concession lines is S 45° W. but the survey, which is an old one, is imperfect and he knows that this direction varies from S 47° W. to S 48° W. or a mean azimuth of 227° 30′. He puts the vernier of the horizontal circle at 227° 30′, and releasing the lower clamp, he turns the instrument in the direction of the picket, fastens the lower clamp and finishes the fine adjustment with the lower tangent screw. The horizontal circle readings are now approximately azimuths.

It is about $9^h\ 40^m$ by the watch. At that hour for latitude 42°, the table gives 358° 43′·1 for the azimuth of the pole star. Releasing the vernier clamp, he puts the vernier at 358° 43′ of the horizontal circle. For the altitude, he subtracts from the latitude, 42° 28′, the number of minutes of the first column of the table opposite $9^h\ 40^m$, which is 37′. He puts the telescope at this altitude, 41° 51′, by the vernier of the vertical circle, and looks for the star which is in the field of the telescope. After finding it, he brings it under the vertical thread, notes the time by the watch, $9^h\ 43^m\ 13^s$, and the horizontal circle reading, 358° 36′·5 (mean of the two verniers).

Releasing the vernier clamp, he turns the vernier plate 180° putting the vernier at 178° 36′·5, and transiting the telescope puts it at the 41° 51′ altitude. He points a second time upon the star, notes the watch time, $9^h\ 45^m\ 39^s$, and the horizontal circle reading, 178° 37′·5. He ends the observation by pointing on the picket and noting the horizontal circle reading, 47° 31′·0 (mean of the two verniers).

He commences the calculation by taking the mean of the two observations. For the sidereal time, he adds the watch correction, $+\ 2^m\ 27^s$, to the mean of the watch times. The + sign indicates that the watch is slow.

The azimuth of the pole star must now be calculated for $9^h\ 46^m\ 53^s$ and latitude 42° 28′. This is done by adding to the tabular azimuth ($9^h\ 40^m$ and 42°) the variation for $6^m\ 53^s$ and 28′. The orientation meridian being east of the observation point, the convergence of meridians has to be added to the azimuth to transform it into a bearing. The departure between the observing station and the orientation meridian, 3·0 miles, is merely measured on the township plan. For latitude 42° 28′, the convergence diagram shows 0′·79 per mile which, multiplied by 3·0 gives 2′·4 for the convergence. The algebraic sum of the azimuth and these three corrections gives for the bearing of the pole star 358° 46′·5, while the mean of the horizontal circle readings is 358° 37′·0. The readings are therefore in error by + 9′·5 and this error has to be added to the mean of the readings on the reference object, 227° 30′·5, in order to give the correct bearing of the latter, 227° 40′.

EXAMPLE NO. 2.

POLE STAR OBSERVATION FOR AZIMUTH

Date: September 27, 1916.
Station: Rigolet, Labrador coast, Quebec.
Station No 2 Lat. 54°10'48" Long. 58°25'15"
Orientation Mer.: Meridian of 59° longitude
Ref. Object: Station No. 1 of traverse.

Face	H.C.R. on R.O.	H.C.R. on Polaris	Watch Time
Right	288° 18·5	1° 44·0	$18^h\ 28^m\ 12^s$
Left	108 17·5	181 45·5	18 29 46
Mean	288° 18·0	1° 44·7	18 28 59
Watch correction			- 3 41
Sidereal Time			$18^h\ 25^m\ 18^s$
Tabular azimuth for $18^h\ 20^m$, lat. 54°			1° 49·8
Variation for $5^m\ 18^s$			+ 0·8
Variation for 10'48" latitude			+ 0·5
Convergence for 23·5 miles west			- 28·2
Bearing of Polaris			1 22·9
H.C.R. on Polaris			1 44·7
Correction of H.C.R.			- 21·8
H.C.R. on Ref. Object			288 18·0
Bearing of Ref. Object			287° 56·2

EXPLANATION.

The surveyor has to make a traverse of the shores of lake Melville, Labrador coast, Quebec. He decides to adopt as orientation meridian the meridian of 59° longitude.

He commences the survey at Rigolet, plants a picket on the shore at station No. 1 of the traverse and sets up his theodolite at the Rigolet point (station No. 2). As there is no known azimuth in this locality he resorts to the compass for directing his telescope on the pole star. The magnetic declination being 37° 12′ west, he puts the vernier of the horizontal circle at 322° 48′, azimuth of magnetic north, and releasing the lower clamp, he turns the instrument until the point of the needle coincides with the zero of its index. He fastens the lower clamp and perfects the adjustment with the lower tangent screw. The horizontal circle readings are now approximately azimuths.

Pointing on the picket, the mean of the horizontal circle readings with the two verniers is 288° 18′·5, which he notes. Time by the watch is about $18^h\ 20^m$: for this hour and latitude 54°, the table gives 1° 49′·8 for the azimuth of the pole star. Releasing the vernier clamp, he puts the vernier at 1° 50′ of the horizontal circle. For the altitude, he subtracts from the latitude, 54° 11′, the number of minutes of the first column of the table, 21′, which gives 53° 50′. He puts the telescope at this altitude and looks for the star which is in the field. After finding it, he brings it under the vertical thread, notes the time by the watch, $18^h\ 28^m\ 12^s$, and the horizontal circle reading, 1° 44′·0 (mean of the two verniers).

Releasing the vernier clamp, he turns the vernier plate around 180°, puts the vernier at 181° 44′, and transiting the telescope puts it at the 53° 50′ altitude. He repeats the observation on the star, notes the time by the watch, $18^h\ 29^m\ 46^s$, and the horizontal circle reading, 181° 45′·5. He ends the observation by pointing on the reference object and noting the horizontal circle reading, 108° 17′·5 (mean of the two verniers).

He commences the calculation by taking the mean of the two observations. For the sidereal time, he adds (algebraically) the watch correction, $-\ 3^m\ 41^s$ to the mean of the watch times. The $-$ sign indicates that the watch is fast.

The azimuth of the pole star must now be calculated for $18^h\ 25^m\ 18^s$ and latitude 54° 10′ 48″. This is done by adding to the tabular azimuth ($18^h\ 20^m$ and 54°) the variation for $5^m\ 18^s$ and 10′ 48″. The orientation meridian being west of the observation point, the convergence of meridians has to be added to the azimuth to change it into a bearing. Measured on the map, the distance from the Rigolet point (station 2) to the meridian of 59° longitude is 23·5 miles. For 54° 11′ latitude, the convergence diagram shows 1′·20 per mile which, multiplied by 23·5, gives 28′·2 for the convergence. The algebraic sum of the azimuth and these three corrections gives for the bearing of the pole star 1° 22′·9 while the mean of the horizontal circle readings is 1° 44′·7. The readings are therefore in error by $-$ 21′·8 and this error has to be added algebraically to the mean of the readings on the reference object, 288° 18′·0, in order to give the correct bearing of the latter, 287° 56′·2.

OBSERVATION FOR SIDEREAL TIME.

For observing the azimuth by the pole star, the watch correction must be known within one minute. This correction must be ascertained from time to time.

The watch may first be set by means of the "Sidereal time at noon, local mean time" given in the tables for the fifteenth of each month. For other dates, the time is calculated by interpolation, the variation being about four minutes per day. Atlantic time is the time of the meridian of 60° longitude, Eastern 75°, Central 90°, Mountain 105° and Pacific 120°. In each of these longitudes, the watch is set to the tabular sidereal time when it is noon, standard time. West of the meridian, if Standard time is used, four minutes must be subtracted from the sidereal time at noon for every degree of longitude west of the meridian: east of the meridian four minutes must be added.

The watch having been set approximately to sidereal time, its correction is ascertained by observing the meridian transit of a star or of the sun. The observation is best made while surveying a line because the theodolite being set up on a line of which the bearing is known, the telescope is readily placed in the meridian by turning the requisite angle. If no line of known bearing exists, the telescope is placed

in the meridian by means of the compass and the pole star, as previously explained.

For a star transit, the telescope, after being placed in the meridian, is put at the altitude of the time star obtained by subtracting the tabular polar distance from the supplement of the latitude. Most of the time stars in the list pass the meridian south of the zenith in the limits of latitude covered by the tables: for the few passing north of the zenith, it should merely be remembered that the altitude calculated as above is reckoned from the south point of the horizon.

The telescope being in position, the field is scanned for the star, a little before transit time, on the side where it enters. With the long diagonal eye-piece, a star south of the zenith enters on the left; with an inverting eye-piece, it enters on the right. The star moves across the field and when it crosses the vertical thread, the watch time is noted.

The following examples show how the observation and the calculation are made and the watch correction deduced.

EXAMPLE NO. 3.

Date.—June 9, 1917.

Station.—Northerly corner of lot No. 1, 7th concession, township of Chatham, Ontario.

Sidereal time of meridian transit of Regulus..	$10^h\ 03^m\ 59^s$
Watch time.....	$10^h\ 01^m\ 32^s$
Watch correction..... +	$2^m\ 27^s$

EXPLANATION.

After completing the azimuth observation of example No. 1, the surveyor calculates the bearing of the reference object by assuming the watch time to be correct: he finds 227° 39′·5. He puts the vernier at 227° 39′·5 of the horizontal circle and points on the reference object with the lower tangent screw: the error of the horizontal circle readings is thus corrected.

The bearing of astronomical north is 360° plus the convergence of meridians, 2°·4, since the orientation meridian is to the east; therefore by putting the vernier at 0°02′·4, the telescope is in the meridian.

Consulting the list of time stars, the surveyor sees that Regulus will cross the meridian in a few minutes ($10^h\ 03^m\ 59^s$). Its meridian altitude is equal to the supplement of the latitude, 137° 32′ less the polar distance, 77° 38′, that is 59° 54′. He sets the telescope at this altitude, observes the transit of the star across the vertical thread and notes the watch time $10^h\ 01^m\ 32^s$. Subtracting this time from the sidereal time of Regulus' meridian transit, he finds for the watch correction $+\ 2^m\ 27^s$. The + sign means that the watch is slow.

EXAMPLE NO. 4.

Date.—September 27, 1916.

Station.—Rigolet, Labrador coast, Quebec, station No. 2 of the traverse.

Sidereal time of meridian transit of Vega.....	$18^h\ 34^m\ 08^s$
Watch time.....	$18^h\ 37^m\ 49^s$
Watch correction.....	$-\ 3^m\ 41^s$

EXPLANATION.

Assuming the watch time to be correct, the calculation of the azimuth observation of example No. 2 gives for the bearing of the reference object (station No. 1 of the traverse) 287° 56′·7. The surveyor puts the vernier at 287° 56′·7 of the horizontal circle and points on the reference object with the lower tangent screw: the error of the horizontal circle readings is thus corrected.

The bearing of astronomical north is 360° minus the convergence of meridians, 28′·2, since the orientation meridian is to the west: therefore by putting the vernier at 359° 31′·8 the telescope is in the meridian.

Consulting the list of time stars, the surveyor sees that Vega will cross the meridian in a few minutes ($18^h\ 34^m\ 08^s$). Its meridian altitude is equal to the supplement of the latitude, 125° 49′, less the polar distance, 51° 18′ that is 74° 31′. He sets the telescope at this altitude, observes the transit of the star across the vertical thread and notes the watch time $18^h\ 37^m\ 49^s$. Subtracting algebraically this time from the sidereal time of Vega's meridian transit, he finds for the watch correction $-\ 3^m\ 41^s$. The $-$ sign means that the watch is fast.

The determination of the watch correction by the meridian transit of the sun is a very convenient method as the sun can be observed through light clouds or haze, when stars are invisible.

The observation is quite simple. The telescope is set in the meridian as previously explained; some bearing or azimuth must, for that purpose, be known with a fair degree of accuracy if the pole star is not visible. The watch times of transit of the first and second limbs across the vertical thread are observed, using, of course, a coloured glass. The right ascension of the sun is calculated by adding to the tabular value of Greenwich apparent noon the variation for the longitude of the place of observation. The product of the variation for one hour, given in the tables, by the longitude expressed in hours, is the variation for longitude. If the longitude is in degrees, it has to be changed to hours and decimals; the change is made at sight with the diagram in the pole star tables.

EXAMPLE NO. 5.

Date.—September 5, 1917.
Station.—Prince Rupert, British Columbia.
Latitude 54° 20′, Longitude 130° 18′.

Right ascension, Greenwich app. noon			10h	54m	50s	
Variation, 9·0 x 8·69				1m	18s	
Right ascension, Prince Rupert app. noon						10h 56m 08
Watch time, first limb	10h	56m	23s			
Watch time, second limb	10h	58m	33s			
Watch time, mean						10h 57m 28
Watch correction						— 1m 20

EXPLANATION.

The observation of the transit of the two limbs is made as explained above. For calculating the right ascension at Prince Rupert apparent noon the longitude 130° 18′ must first be converted to hours: the diagram in the tables shows $8^h \cdot 69$. Multiplying by the variation for one hour, $9^s \cdot 0$, the product 78^s is added to the tabular right ascension, $10^h\ 54^m\ 50^s$ which gives $10^h\ 56^m\ 08^s$ for the right ascension at Prince Rupert. apparent noon. Subtracting from this right ascension the mean watch time of transit, $10^h\ 57^m\ 28^s$ gives $-\ 1^m\ 20^s$ for the watch correction. The — sign means that the watch is fast.